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ENGINEER DEPARTMENT, U. S. ARMY.

THE WATER-JET

AS AN

AID TO ENGINEERING CONSTRUCTION.

A HISTORICAL SKETCH

OF ITS APPLICATION TO THE SINKING OF PILES AND CAISSONS AND THE REMOVAL OF SAND BARS AND OTHER ACCIDENTAL DEPOSITS;

WITH

A DESCRIPTION OF THE METHOD EMPLOYED IN DRIVING SHEET PILES FOR THE PIERS AT THE HARBORS OF

TWO RIVERS, ALGAPEE, AND STURGEON BAY, WISCONSIN.

BY

L. Y. SCHERMERHORN, C. E.,

AND

HENRY M. ROBERT,

Major of Engineers, U. S. Army.

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TWO RIVERS, AHNAPEE, AND STURGEON BAY,

WISCONSIN.

BY

L. Y. SCHERMERHORN, C. E.,

UNDER THE DIRECTION OF

HENRY M. ROBERT,

MAJOR OF ENGINEERS, U. S. ARMY.

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United States Engineer Office,

Milwaukee, Wis., April 6, 1881.

Sir: I have the honor to forward herewith a report on the use of the water-jet by Assistant Engineer L. Y. Schermerhorn, with the recommendation that it be published.

In connection with using the water-jet in driving sheet-piling for a lining to the pile piers at Two Rivers Harbor, Wisconsin, in 1878, I had occasion to investigate the question as to the various uses to which the water-jet had been applied in civil engineering. Since that time I have used the water-jet at two other harbors, Ahnapee and Sturgeon Bay, with good results so far as can be now seen. Having received several inquiries for information upon the subject, it occurred to me that a brief statement of the results of these investigations and of the experience at the works mentioned might be of sufficient value to justify publication.

Assistant Engineer L. Y. Schermerhorn has had for years a deep interest in the use of the water-jet, and to his intelligent oversight of the work, assisted by Mr. Charles Crosman, overseer, is due the fact that the United States did at the same expense nearly 50 per cent. more work in driving sheet-piling than was done by able contractors at the same place last fall, both using the water-jet. The paper prepared by Mr. Schermerhorn gives the methods of driving piles by the use of the water-jet in sufficient detail to enable anyone else to use the jet intelligently from the start. He has also placed in the paper much valuable information as to the use of the jet for other purposes than driving sheet-piling.

In the first part of the paper references in foot-notes are made occasionally to letters. These letters were in answer to a circular sent out by me in 1879 to various civil engineers and to all officers of the United States Corps of Engineers in charge of works, asking for information on this subject coming within the range of their personal knowledge.

From this paper it will be seen that while the water-jet is of great value in sand, its value is greatly reduced if there is any gravel or clay mixed with the sand, and that where there is much gravel it is practically useless.

Very respectfully, your obedient servant,

HENRY M. ROBERT,
Major of Engineers, U. S. Army.

The CHIEF OF ENGINEERS, U. S. ARMY,
Washington, D. C.

OFFICE OF THE CHIEF OF ENGINEERS,
UNITED STATES ARMY,
Washington, D. C., April 12, 1881.

Respectfully submitted to the honorable the Secretary of War, with recommendation that this paper be printed, and that 500 copies be obtained for the use of the Corps of Engineers on the usual requisition.

JOHN G. PARKE,
Acting Chief of Engineers.

Approved:

By order of the Secretary of War:

H. T. CROSBY,
Chief Clerk.

APRIL 14, 1881.

THE WATER-JET AS AN AID TO ENGINEERING CONSTRUCTION.

United States Engineer Office,
Milwaukee, Wis., April 6, 1880.

Sir: Inquiries for information concerning the details followed, and results obtained, in the use of the water-jet as an aid in engineering constructions, have led to the following compilation of methods and facts concerning its application.

When a sufficiently powerful stream of water (jet) is forced into sand, silt, mud, or soft clay, a rapid disintegration and removal of the material ensues when the action of the jet is confined to quite limited areas; and an increased fluidity of the earthy mass with a partial excavation when not so confined. In either case the action of the water-jet facilitates the passage of piles, cylinders, caissons, or similar constructions through earthy material.

A compilation of all known applications of the water-jet indicates that its first use arose from the difficulties experienced in obtaining suitable foundations for light-houses and wharves on the sandy shores of the Gulf and Atlantic Southern States. In several cases the engineering difficulties of the occasion have led to the use of the water-jet without the user being aware of its previous application to similar difficulties. This has led to claims of originality from several independent sources. In the examinations upon which this report is based, the earliest determined use occurred in 1852, in sinking piles for wharf and warehouse at Decrow's Point, Matagorda Bay, Texas; and seems to have arisen from a suggestion made by Lieut. Geo. B. McClellan, U. S. E., who was at the time chief engineer of the Department of Texas, and in charge of surveys of rivers and harbors on the coast of Texas.

The method adopted is described by an eye-witness, Mr. A. J. Moore, as follows: *

* * * In February, 1852, * * * a resident of Decrow's Point was building a wharf and warehouse and found it difficult to sink the piles in the hard sand bottom. Captain McClellan advised him to get a hand-pump and pump them down; which he did, and it worked finely. * * * The method was as follows: * * * water was forced through an ordinary rubber hose, with a piece of gas-pipe on the end for a nozzle. The nozzle was placed close to the point of the pile on the bottom, the jet of water * * * scouring the sand away from the pile and making a hole, in which the pile sunk rapidly.

* Letter of Mr. A. J. Moore, May 6, 1879.

In 1854, in sinking piles for the foundation of Pungateague Light, Chesapeake Bay, Mr. Charles Pontez, under direction of Major H. Bache, U. S. T. E., suggested the use of the water-jet. Mr. Pontez thus describes the method: *

The piles were hollow, of cast-iron, 18 feet long, 7 inches in diameter, with a trumpet-shaped base flaring out to 3 feet in diameter. A 1-inch iron pipe, which passed through the pile, was connected by a hose with a hand force-pump. By this means a pile was sunk 11 feet in 2½ hours; * * * 11 piles were sunk in three days.

Between 1854 and 1861 Lieut. W. H. Stevens, U. S. E., made use of the water-jet for sinking sheet and bearing piles in the construction of jetties for the protection of Fort Livingston, Louisiana; for the sinking of wooden piles for platform, and screw-piles for foundation for a light-house at Half-Moon Shoals, Matagorda Bay, Texas, and at Ship Shoals, Louisiana; and for sinking wooden piles for the foundation of a wharf and warehouse in connection with the fortifications at Pelican Spit, Galveston Bay, Texas. It has been impossible to obtain the details of the methods of application of the water-jet at the foregoing works; but such details as are obtainable indicate that the water-jet was not attached to the piles.

In 1856 James Brunlee used the water-jet as an aid in sinking cast-iron piles for the foundations of the Kent and Leven Viaducts over Morecambe Bay, England.† The piles were hollow, pointed, and provided with a disk near their lower ends. A wrought-iron pipe 2 inches in diameter was carried down the inside of the piles, and through the ends to a distance of about 2 feet below the point of the pile. The top of the pipe was connected by a flexible hose with the force-pump. By these appliances the water was forced down the pipe and into the sand, which being loosened and rendered quite fluid permitted the easy descent of the piles. The guide piles forming the approach to the draw-bridge were baulks of timber, 14 inches square, fitted with cast-iron sockets having disks 2½ feet in diameter. These piles were sunk by the same method as the cast-iron piles, except that the water-jet was carried down the outside of the pile to its point. Since this application of the water-jet by Mr. Brunlee, its use has been quite frequent in the construction of foundations for light-houses on the coasts of England and France.

In 1862, 5,000 wooden piles were placed by Mr. J. W. Glenn across the channel to Mobile Harbor for the purpose of obstructing the entrance of the Federal fleet. The general details were as follows:‡

* Letter from Mr. C. Pontez, April 8, 1879. Scientific American, July 13, 1878. Ex. Doc. 10, 34th Cong., 1st session.

† Permanent way of European Railways, page 43. Proceedings Inst. of Civil Engineers, vol. xvii, page 442. Wood's "Mahan," page 229. Spon's Dictionary of Engineering, page 2643. Vose's Manual for Railway Engineers, page 305. Van Nostrand's Engineering Magazine, April, 1868, page 360. Trautwine's Engineer's Pocket Book, page 325. Cast and Wrought-Iron Bridges, by William Humber.

‡ Van Nostrand's Engineering Magazine, 1874, pages 360 and 513. Scientific American, July 13, 1878, page 20. Supplement, No. 141, September 14, 1878.

The piles were from 20 to 30 feet in length, with a diameter of from 18 to 30 inches. They were sunk 12 to 20 feet in the sand, and their tops cut off a little below the surface of the water. A steam fire-engine placed on the deck of a steamer supplied the necessary force-pump. At the end of about 50 feet of hose an ordinary 1¼-inch fire-nozzle was placed. At the lower end of the pile two iron staples were driven, in which the nozzle was secured while the pile was being sunk. The pump was started, and the pile, with the jet attached, lowered to the bottom, into which it quickly sunk to the required depth. The hose and nozzle were freed by drawing them to the surface before the pump was stopped. The rate of penetration is stated as "about 1 foot per second." The depth of water was about 8 feet; and the bottom is described as being "for a depth of 20 feet a deposit of sand such as is common to the Gulf coast."

In the Gulf States palmetto piles were found to quite effectually resist the ravages of the teredo; but the wood is too soft to withstand the blows of the pile-driver. By using the water-jet the necessity for the use of the pile-hammer was removed, and palmetto piles became available. This, taken in connection with the favorable results previously obtained by Lieut. W. H. Stevens, led to quite a general use of the water-jet in sinking both round and sheet piles at various points along the Atlantic and Gulf coasts. Application of the principle was made by Major P. C. Hains, U. S. E., in 1872, in the construction of the foundations for Thimble Light, Virginia, and in 1873 in the construction of range lights at the mouth of the Patapsco River, Maryland; by Capt. A. N. Damrell, U. S. E., in 1873, in placing piles, for beach protection, at Fort Gaines, Mobile Bay, Alabama, and in 1877 for sheet-piling for sea-walls at Fort Morgan, Mobile Bay; by Capt. C. E. L. B. Davis, U. S. E., in 1874–'75 and '77, in the construction of sheet-piling at Galveston Bay, Texas.

From 1867 to 1869, O. Chanute, C. E., chief engineer of the Kansas City bridge, made use of the water-jet* in sinking wooden bearing-piles, by passing an iron pipe along the side of the pile and attached thereto, allowing the jet to discharge near the point of the pile. Mr. Chanute also used compound piles, formed by bolting together four square pieces of timber, one corner of each piece having been chamfered, and these chamfered edges placed together, leaving a hole along the axis of the pile through which the jet was forced. The water-jet was used, also, in sinking the caisson for pier No. 4, by arranging jets so as to discharge at the lower edge of the caisson; also by independent jets directed by divers against special points of resistance.

In 1868, Mr. T. J. Whitman, C. E., chief engineer of the Saint Louis

*Vose's Manual for Railway Engineers, pages 315, 317. Van Nostrand's Engineering Magazine, vol. iii, page 406. Monograph on Kansas City Bridge, by O. Chanute, N. Y. Van Nostrand.

water-works, made the following application of the water-jet in sinking sheet-piling for the coffer-dam about the foundations of the river engines:*

A 2-inch iron pipe was fastened to the side of the pile; the lower end of the pipe was contracted to a ¾-inch opening. The pipe was bent so as to bring the nozzle just to the point of the pile. The pipe was connected with the pump by a 3-inch hose, through which water was forced with the greatest pressure obtainable. A second method of application was to bore a hole from the point of the pile upward (along the axis of the pile) for about 2 feet, and a second hole from the side of the pile obliquely downward to intersect the first hole. The nozzle of the pipe was forced into the oblique hole and the water pumped as before. By this latter method the piles could be sunk much faster than by the first.

Difficulty was found to exist in sinking the piles to the required depth, the cause of which, Mr. Whitman says, was as follows:

When we excavated for the masonry the difficulty was made evident. The material was sand mixed with a considerable amount of gravel and some quite large stones. The pile would sink quite readily through the sand and fine gravel, but when it had passed through a certain amount of this material the gravel collected in a pocket about the foot of the pile and allowed the water to escape without displacing the material, so that the pile would sink no further.

In 1870, E. D. Mason, C. E., chief engineer of the Hannibal bridge, Missouri, used the water-jet to clear away the sand from the piles so that they could be cut off below the river bottom; also to generally remove deposits from about the foundations.†

In 1871, Capt. M. R. Brown, U. S. E., under direction of Lieut. Col. J. D. Kurtz, U. S. E., made valuable application of the water-jet in sinking the iron screw-piles used in the construction of the piers at Lewes, Delaware.‡ The piles consisted of solid wrought-iron shafts from 5¼ to 8½ inches in diameter, provided with cast-iron screws from 2 to 2½ feet in diameter. In attempting to screw the piles down they broke, from the extreme resistance of the material into which they were forced, before they had attained the necessary depth. Attempt was made to reduce the resistance by leading a jet of water to the material underneath the flanges of the screw; the prevalence of gravel and insufficient force of the pump led to unsatisfactory results. An examination of a broken screw led to the conclusion "that the greatest resistance encountered is on the upper surfaces of the (screw) flanges, and is doubtless due to the friction caused by the direct weight of the superimposed cone of sand and to the opposition of a component of this weight to the motion of the screw-flanges."

It was thought that if a jet of water were forced on the upper surfaces of the screw-flanges it would accomplish the more complete liquidity of the sand above the screw, and change the volume of pressure on the flanges from that of an inverted cone to that of a cylinder whose diameter would be equal to that of the smaller face of the frustrum. Streams of water through two 1¼-inch iron pipes were led directly upon the flanges and the

* Letter of T. J. Whitman, September 15, 1879.

† Van Nostrand's Engineering Magazine, vol. v, page 308.

‡ Reports of the Chief of Engineers, U. S. A., 1872, 759, 770; 1873, 860, 861; 1874, II, 131; 1879, 447.

hitherto great resistance to screwing down the piles at once ceased. A subsequent determination of resistances to screwing down the piles developed the fact that nine-tenths of the resistance disappeared upon the proper application of the water-jet to the upper surfaces of the screw-flanges. Through the aid of this application of the water-jet it became possible "to settle the screw-piles as deeply as was deemed necessary in a bottom where, without the jet, the strongest iron screws were broken as though they had been of glass, when main force alone was used in an unsuccessful effort to sink them more than 4 feet." From the experience gained on this work it was inferred that with the aid of the jet there would be no great difficulty in penetrating to a depth of 20 feet, since the last foot of work in penetrating 12 feet was accomplished, seemingly, as easily as the first foot of the same stratum. Subsequently, when it became necessary to remove some of the piles, the application of the water-jet to the upper face of the screw rendered its removal quite easy, when previous efforts by backing the screw or raising the pile bodily had proved unsuccessful.

In 1873, C. C. Martin, C. E., superintending engineer of the New York and Brooklyn bridge, made the following application of the water-jet in placing sheet-piling:* The sheet-plank were 8 by 2 inches, and it was found that from 30 to 40 blows were required to drive a plank 1 inch. It was then concluded that the water-jet might aid the descent of the sheet-plank. A $\frac{3}{4}$-inch hose was attached to a $\frac{3}{4}$-inch iron pipe about 3 feet in length. This pipe was introduced along the side of the sheet-plank, and the water from a city hydrant—with a pressure of about 50 pounds per square inch—was turned on; this loosened the sand, and the pile was driven easily. The following comparative results will show the effective action of the water-jet. A sheet-plank without the aid of the jet required 392 blows to drive the plank 10 inches in 18 minutes; while by the aid of the jet another plank, similarly placed, required 93 blows to drive the plank $17\frac{1}{2}$ inches in 2 minutes.

In 1874, G. Jordan, C. E., in the construction of the piers for a bridge over the Tensas River, Alabama, made use of large iron cylinders from 4 to 6 feet in diameter, which were sunk to the required depth by the aid of a series of jets applied concentrically with the inner sides of the cylinders and discharging from vertical pipes at the lower edge of the cylinders.†

In 1875, Mr. C. Fitzsimmons applied the water-jet to facilitate the sinking of the shafts of the Fullerton Avenue conduit, Chicago.‡ The brick-work was built on an iron shoe and sunk from the surface of the ground; at times the pressure of the sand against the sides of the shaft was so great as to prevent its sinking. The application of the water-jet along

* Letter of Mr. C. C. Martin, January 31, 1879.
† Van Nostrand's Engineering Magazine, 1874, page 360.
‡ Letter of C. Fitzsimmons, February 27, 1879.

the sides of the shaft diminished the resistance and greatly facilitated its descent.

In 1877, Messrs. Stocklin & Vetelart, contractors for the enlargement of Calais Harbor, France, used the water-jet in combination with an ordinary pile-driver under the following circumstances:* Guide-piles 9 inches square and placed 6½ feet apart were driven ten feet into the bottom; between the guide-piles sheathing planks, 4 inches thick, were driven to a depth of 8 feet. The pile-driver ram weighed 1,200 pounds and could be given a fall of six feet. The water was injected from two pipes, one on each side of the pile, their orifices being about one foot below the point of the pile. The pipes were kept as nearly vertical as possible and in constant motion. Without the aid of the jet 185 blows were required to drive a guide-pile 10 feet, and 900 blows were required to drive a panel (6½ feet) of sheet-plank to a depth of 8 feet. The time required for pitching and driving a panel was 8 hours and 36 minutes. By the aid of the water-jet the number of blows required for a panel was from 0 to 50, and the time 1 hour and 9 minutes. The system was said to have the additional advantage of permitting the sheathing to be placed much closer and in better alignment than could be done by the hammer alone.

At many of the lake harbors the piers, extending from the shore-line to about the 12-foot curve, consist of two parallel rows of round piles, 14 feet apart. The piles of each row are driven as closely together as possible, cut off at the surface of the water, and surmounted by a timber superstructure about 5 feet in height. The filling of these piers consists of brush, slabs, and stone. Experience has demonstrated that such piers readily permit the passage of sand through them from the outside into the channel between the piers, rendering necessary some subsequent device to make them sand-tight. The harbors at Two Rivers, Ahnapee, and Sturgeon Bay, Lake Michigan, were formed in part by piers constructed as above described. In 1878, Maj. H. M. Robert, U. S. E., whose district embraces the above harbors, after a careful examination of possible expedients for rendering them sand-tight, decided to place sheet-piling along the side of the pile-piers. The work was begun in the fall of 1878 and continued during the seasons of 1879 and '80. The amount of pile-pier revetted with sheet-piling was nearly 4,100 linear feet, and it is believed that the methods adopted and the results obtained justify detailed description. The general method of construction was as follows:† The sheet-pile revetment consisted of a double row of plank, each 3 inches in thickness, 12 inches in width, and 18 feet in length; the plank breaking joints with each other and extending from the top of the superstructure to 13 feet below the water-surface; secured to the pile-pier by an oak wale 6 by 12 inches,

* Journal Franklin Institute, 1878, page 275. Ann. des Ponts et Chaussées, 5th Series, vol. xv, page 74.

† See cut, Report of the Chief of Engineers 1879, page 1512.

placed at the water-surface, and a pine wale 8 by 12 inches, along the top of the superstructure; the wales were attached to the timber-work of the superstructure by 1⅛-inch screw-bolts. The sheet-piling was generally placed along the harbor side of the piers. The general depth of water along the piers was from 2 to 11 feet, so that the plank was sunk from 11 to 2 feet into the lake bottom; the material into which the sheet-piling was driven was generally sand—in a few instances small quantities of clay or gravel occurred. Since the object of the sheet-pile revetment was to render the piers impervious to sand, it was of the first importance that the sheet-piles should be in intimate contact, and free from the openings which occur in sheet-piling placed by the usual methods. It was considered that the water-jet furnished a method for placing the sheet-piles so that they would be practically sand-tight. The results accomplished at Two Rivers, Ahnapee, and Sturgeon Bay, Wisconsin, justify these anticipations. The work at Two Rivers was the first undertaken, and was to a certain extent tentative. As the work progressed experience indicated modifications of the original conception, which grew into the methods used at Ahnapee and Sturgeon Bay, from which the best results were obtained.

The following is derived from the report of Mr. Chas. Crosman, under whose local direction the work was carried on:

The plant consisted of a vertical tubular boiler, with an attached engine having an 8 by 12 inch cylinder, and giving about 130 revolutions per minute to a 42-inch driving-wheel. A No. 4 Holly rotary pump, with an 18-inch pulley, was attached by a belt to the driving-wheel of the engine, giving about 300 revolutions per minute to the pump. The rotary pump was selected for the following reasons:

(1.) Its small cost when compared with a direct-acting steam-pump of equal capacity.

(2.) The action of the jet surcharged the water in the vicinity of the pump suction with sand; this would have proved highly destructive to the cylinders of a direct-acting pump, or else rendered necessary a troublesome method of compensation.

The rotary pump, by an easy and permanent device, allows for the wear incident to the use of sandy water. The pump was supplied with a 4-inch suction, and discharged through a 3-inch hose about 50 feet in length. The hose was provided with a nozzle 3 feet in length and 2 inches in diameter.

The engine was provided with a hoisting drum capable of giving motion to an 1800-pound hammer, moving in the leaders 24 feet in height. The boiler, engine, pump, and pile-driver were mounted on a platform 12 feet wide and 24 feet in length, carried on wooden rollers which admitted of its being readily moved backward or forward along the top of the pier as occasion required. From the main platform a smaller platform, about 6 feet wide and 10 feet long, was suspended so as to be about 1 foot above the water-surface, allowing ready access to the face of the pier.

The previously described nozzle was securely attached to the end of a pole about 2 inches in diameter and 18 feet in length; the pole being used to guide the jet into place and force it into the sand.

For driving sheet-piles only, eight men were required,* stationed as follows. One man (*a*) on the pier, one man (*b*) on the main platform, four men (*c, d, e, f*) on the suspended platform. Everything being in readiness, *a* slides a plank from the pier into the water and passes it along to *c*, who hooks the hoisting line to it. In the mean time *d* passes the pole—with attached nozzle—to *e*, who presses it into the lake bottom at the place to be

*The engineer and fireman are not designated by letters.

occupied by the sheet-plank. When the required depth has been reached by the jet, *d* takes the pole and raises the nozzle to about the natural bed of the lake; *c* gives the signal to *b*, who then raises the plank into position between the leaders by aid of the rope that passes to the winch-head of the hoisting engine; *e*, with a cant-hook, keeps the face of the plank against the pier, while *f* presses its edge close to the edge of the plank last driven, in the same row; *b* lets the sheet-plank drop as far as it will into place, unhooks the hoisting line and steps upon the top of the sheet-pile to press it entirely down into place. Ordinarily his weight alone was sufficient to accomplish this, though sometimes it was necessary for one of the men on the suspended platform to assist him by pressing on the head of the sheet-pile with a handspike or lever; *c* then spikes the sheet-plank at the water-surface and near the top of the superstructure. While the next plank was coming, the platform was moved forward or backward as required by *b*, through the aid of blocks and falls leading to the winch-head of the engine.

The jet became almost powerless when required to force its way through drift-wood, chips, sunken logs, or stone; and, since such obstructions generally existed along the side of the piers, it was found necessary to remove them by dredging a narrow cut close to the pier. No effort was made to utilize the increased depth of water obtainable immediately after dredging, since in sand clear of obstructions such as are mentioned above, the jet permits the placing of the sheet-plank in 8 feet of sand as readily as in a lesser depth.

The sheet-piles did not generally require sharpening; experience developing the fact that the piles were placed neither more rapidly nor in better position by being sharpened. The pile-hammer previously described was seldom used—not more than one plank in one hundred requiring its assistance. This adds largely to the value of the water-jet, since in driving sheet-piles by the hammer, oak, or timber equally capable of resisting the destructive effects of impact, would be required; by using the water-jet the necessity of the hammer is removed, and pine timber can be substituted for oak, reducing thereby the cost of this item about one-half.

The following rates of progress were obtained by Mr. Crosman:

Maximum number of sheet-piles driven in one day (ten hours)	196
Minimum number of sheet-piles driven in one day (ten hours)	105
Average number of sheet-piles driven in one day (ten hours)	130

The following exceptional rates were obtained:

August 9, 1880, 47 sheet-piles placed in one hour.
August 10,1880, 150 sheet-piles placed in five hours.

These piles were all 12 inches wide, 3 inches thick, and 18 feet in length, and sunk to an average depth in the sand of 8 feet.

The following is a detailed statement of the entire cost, per linear foot, of revetting 2,012 linear feet of pile-pier at Ahnapee and Sturgeon Bay:

Screw and drift-bolts, and spikes	$0.46
Lumber	1.59
Labor, entire pay-rolls	0.94
Supplies, fuel, oil, waste, and small tools	0.12
Dredging to remove obstructions	0.67
Superintendence, exclusive of office	0.39
Total cost per linear foot	$4.17

The foregoing does not include the cost of machinery or plant, which will be subsequently considered.

The application of the item "labor" was as follows:

Preparatory work in starting operations.
Framing and handling timber.
Riprapping sheet-pile revetment.
Watchman and repairs.
Driving sheet-piles.

In the above statement of cost the item of "labor" amounted to 94 cents per linear foot of pier revetted. Of this amount about 24 cents was applied to the subdivision "driving sheet-piles," leaving 70 cents to be distributed among the other subdivisions. This reduction of the item "driving sheet-piling" to about one-quarter of the cost of all labor is believed to be largely due to the application of the water-jet in placing the sheet-piling.

The prices paid for the material used were as follows:

Screw and drift-bolts, and spikes, per pound	4½ to 5 cents.
Pine lumber, delivered, per M feet	$12.00
Oak lumber, delivered, per M feet	30.00
Labor: One master carpenter, per month	$80.00
One engine-driver, per month	55.00
One carpenter, per day	2.50
Eight laborers, per day, each	1.50
One watchman, per day	1.50
Dredging, per working hour	10.00
Superintendence, one overseer, per month	150.00

The engine and boiler and many of the small tools used had been previously purchased for other work. The estimated cost of the entire plant, if purchased especially for the work, would be about as follows:

Boiler, with pile-driver engine attached	$800.00
Rotary pump, with belt, pulleys, suction-pipe, and hose	325.00
Movable platform, with pile-driving hammer and leaders attached	250.00
Blocks, rope, and tools	75.00
Hoisting-drum and fixtures	150.00
	$1,600.00

A recent application of the water-jet was made by C. Macdonald, C. E., president of the Delaware Bridge Company, in building the iron ocean-pier at Coney Island. The following brief description * of the methods used and results obtained is of interest. The pier was built to furnish means of landing from steamers and to afford increased facilities for promenades at Coney Island beach. The pier was supported on hollow wrought-iron piles 8⅝ inches outside diameter, metal ½ inch in thickness. The bases of the piles were provided with cast-iron disks 2 feet in diameter and 9 inches deep, through which was an opening 2 inches in diameter for the passage of the water-jet. The piles were sunk from 10 to 17 feet into the sand.

* Monograph by C. Macdonald, C. E., on "The Ocean-Pier at Coney Island." American Society of Civil Engineers.

In the operation of sinking the piles the water-jet was applied through a pipe 1½ inches in diameter, extending through the pile and disk, and about 2 inches beyond. * * * The pumping plant consisted of a Worthington pump with a steam cylinder 12 by 8½ inches, and a water cylinder 8½ by 7½ inches. * * * Also a No. 6 Cameron pump with a 10 by 9 inch steam, and a 10 by 6 inch water cylinder. The suction-pipes were 4 inches in diameter and the discharging hose 3 inches in diameter. The boiler was upright, 42 inches in diameter, 8 feet high, and containing 62 tubes 2 inches in diameter.

With the power above described it was found that piles could be driven in clear sand at the rate of 3 feet per minute to a depth of 12 feet; after that the rate of progress gradually diminished until at 18 feet a limit was reached beyond which it was impracticable to go without considerable loss of time.

A few disks 2½ feet in diameter were tried, but much more time was required in sinking them. One 3-foot disk caused a delay of six hours in sinking 15 feet through very uniform sand.

The experiment was made—late in the progress of the work—of forcing the water directly through the pile instead of through the inner pipe, previously referred to; so that the water from the pump was discharged from the bottom of the pile through a 2-inch opening. "In this case the pile sunk much more rapidly than before," and the pressure on the hose indicated that the resistance to discharge was materially reduced.

Upon one or two occasions it became necessary to raise piles which, by mistake, had been driven to a greater depth than required and allowed to become firmly settled. This was accomplished by passing a jet down and around the outside of the pile until the disk was reached, when the pile was easily raised by the blocks attached to the hoisting engine, and finally secured at the proper level.

The limit of safe loading for piles of this character has been assumed to be 5 tons per square foot of disk. * * * Many of these piles sustain a load, due to structure alone, of 6.3 tons per square foot of disk; to this must be added the weight of moving masses of people and exceptional local loads, which have, in some cases increased the pressure upon the disk to 8 tons per square foot, without causing any settlement which can be detected by the eye. This extreme practice is not recommended where absolute rigidity of foundation is required.

It frequently happened in sinking, that the pile would bring up on some tenacious material which was assumed to be clay, and through which the jet unaided could not be made to force a passage. In such cases it was found that by raising the pile about 6 inches and allowing it to suddenly drop with the jet still in operation, and repeating as rapidly as possible, the obstruction was finally overcome; although in some instances five or six hours were consumed in sinking as many feet. The deposits thus retarding the action of the jet were assumed to be clay pockets.

The wooden piles around the pier-head were driven by a water-jet; the 1½-inch tube, previously used for the iron piles, was lashed to the side of the wooden pile at the top, and held in place at the bottom by cleats nailed to the sides of the piles. * * * It was not found necessary to curve the pipe so as to bring the jet under the center of the piles. They did not manifest any tendency to work over to the side on which the tube was secured. * * These piles were of pin oak * * * and were settled to a depth of 12 feet without the aid of a hammer; but much time would be saved by the use of a regular pile-driver *in connection with the water-jet* where lighter piles are used or greater depths required.

The general principle upon which the efficiency of the jet—in sinking piles—depends, is the increased fluidity given to the material into which

the piles are sunk. The actual displacement of material is small; hence the efficiency of the jet is greatest in clear sand, mud, or soft clay. In gravel, or in sand containing a large percentage of gravel, or in hard clay, the jet is almost useless.

For these reasons the engine, pump, hose, and nozzle should be arranged to deliver large quantities of water with a moderate force, rather than smaller quantities with high initial velocity. In gravel, or in sand containing considerable gravel, some benefit might result from a high and concentrated velocity, sufficient to absolutely displace the pebbles and drive them from the vicinity of the pile; but it is evident that any practicable velocity would be powerless in gravel except for a very limited depth, or where circumstances favored the prompt removal of the pebbles.

The error most frequently made in the application of the water-jet is the insufficient capacity of the pumps employed. In almost every application alluded to in this report the efficiency of the jet would have been largely increased if the pumps and hose supplying the jets had been of much larger capacity. It is also highly probable that the rude iron nozzles generally used could, with advantage, be replaced by nozzles constructed and proportioned so as to give, as nearly as possible, perfect contraction to the fluid vein.

In addition to the foregoing applications of the water-jet, it has been proposed to utilize its disturbing action on sand, in removing bars in rivers, by a suitable arrangement of powerful jets attached to the hull of a vessel and enabling the vessel to cut its way through obstructing bars.*

The water-jet has also been of great aid in removing snags by loosening the sand over deeply imbedded snags, thereby greatly facilitating their removal.†

In making borings through sand, mud, or soft clay, the water-jet has proven of great advantage. By its aid an iron pipe can be easily and quickly sunk to a great depth, or until impervious material is encountered.‡

On Diamond Reef, in New York Harbor, the water-jet was used to remove deposits of clay and imbedded bowlders.§ A Worthington duplex pump, with water cylinders 10¼ inches in diameter and 10 inches stroke, supplied "two streams through 100 feet of 2½-inch hose, with 1¼-inch nozzles, under a pressure of 150 pounds per square inch." The nozzles, by the aid of attached spars, were forced downward into the material to be removed. "The nozzles penetrated ordinarily about 1 foot per minute to a depth of 5 or 6 feet, making a cavity from 3 to 5 feet in diameter; the clay and sand being washed away and the stones sinking to the bottom." Bowlders, the largest of which were 10 feet in diameter and 7 feet in

* Report of the Chief of Engineers, 1868, 671; '69, 310; '70, 340.
† Report of the Chief of Engineers, 1873, 614, 616.
‡ Report of the Chief of Engineers, 1874, I. 724; '75, I, 235; '79, 393.
§ Report of the Chief of Engineers, 1879, 62, 382.

height, were undermined and sunk below the requisite depth, or washed out of the clay and removed. Where the position of the material was unfavorable for its ready removal by the currents, use was made of a wrought-iron pipe 15 inches in diameter and 64 feet in length, through which powerful currents were induced by means of a water-jet introduced in the large pipe. The object of this pipe was to carry off the material disintegrated by the action of another jet operating upon the material to be removed. By means of the induced current a velocity of 10 feet per second was obtained through the large pipe, which was sufficient to bring into the pipe sand, gravel, and stones as large as could pass the injector nozzle, and to project them some feet beyond its outer end. The capacity of the machine was estimated at from 50 to 100 tons of material per day. For this device and this method of excavation a patent was granted to Roy Stone, of New York.

The machine has been improved by dividing the ejector jet into two exterior converging nozzles, placed opposite each other and entering the pipe at a very sharp angle, thus relieving the pipe of all obstruction to the flow of water and material through it; by using a bell-mouth receiver to facilitate the entrance of water into the pipe, and by arranging the loosening jet-nozzle and pipe so that the direction of its discharge can be changed at the will of the operator.

A faithful effort has been made to incorporate in this paper all information obtainable, and if valuable applications of the water-jet have been made public and not herein incorporated, the omission is unintentional and not due to negligence. In several cases applications have been made which the users thought original, but which this paper shows had been anticipated by others. In such cases, while not properly originators, they are entitled to none the less credit for ingenuity and adaptation of resources to the accomplishment of ends.

Very respectfully, your obedient servant,

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